A FRAMEWORK FOR ANALOG STUDIES OF MARS SURFACE OPERATIONS

Using the Flashline Mars Arctic Research Station

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Introduction

In July 2000 the Mars Society constructed a habitat on Devon Island near Haughton Crater[2], with the objective of promoting research on how people will live and work on Mars. The design of this habitat, called the Flashline Mars Arctic Research Station (FMARS; informally, "the hab") has been influenced by NASA's Reference Mission studies (Hoffman, 1997) and related plans for a Mars habitat (Zubrin, 1996; Micheels, 1999). The two-story 8m-diameter structure of FMARS will house scientists and engineers who will investigate the geology and biology of the nearby terrain while experimenting with alternative habitat layouts, prototype instruments, communication tools, space suits and gloves, rovers, communications and support from remote teams, operational procedures, and so on, that might be used on Mars.

Using FMARS as a research facility requires a framework for systematically defining and evaluating prototype designs and experimental protocols. This paper describes the current configuration of the hab (as built July 2000), dimensions of research that might be undertaken and expected contributions, ways of characterizing fidelity of analog studies, experimental scenarios, and management recommendations.

Many analog studies have been conducted with an eye towards future, long-duration space travel. The focus has been primarily on the effects of isolation and confinement. Winter-over stays in Antarctica have been considered (e.g., Harrison, Clearwater, and McKay, 1991), as well as crews on submarines and Skylab (Connors, Harrison, and Akins, 1985). Stuster (1996) provides a commanding survey of data and

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[2] Haughton is a relatively uneroded 23.4 million year old impact structure, located near the western end of Devon Island in the Canadian Arctic Archipelago; it is the highest-latitude terrestrial impact crater known (75º 22' N, 89º 41' W) (Osinski, et al., 2000). The crater is approximately 500 miles north of the Arctic Circle and over 100 miles from the northernmost commercial airport on Earth, in Resolute.

recommendations from these settings and historical naval expeditions. In these studies we learn from corresponding settings and activities how people might behave during long-duration missions in confined habitats, and how to organize crews, activities, and facilities to foster good health and social well-being.

However, by virtue of focusing on people confined to small spaces, with limited communication with the rest of humanity, few of these studies have considered the nature of extensive surface exploration, nor how an isolated crew will work with a remote support team. This is the benefit offered by FMARS, in its open setting with authentic work on Devon Island, yet with only a restricted interior space in an isolated, harsh environment having limited natural resources. Thus building on prior work, we can take analog studies to a new dimension, in which more aspects of a realistic Mars exploration scenario are incorporated, such as weather prediction, surface navigation, rover assistants, deployed scientific instruments, geological sample analysis, remote collaboration, etc. The notion of “analog” then broadens from the idea of long-duration isolation and confinement to embrace the larger system of environment, exploration, and communications that will constitute a Mars surface operation. Rather than focusing so much on the psychology of stress, we can consider learning and improvisation, research collaboration at a distance, and how machines can be designed to complement human capabilities. Doing this well in the FMARS analog setting involves carefully analyzing the relation between Devon and Mars, so interactions between factors can be understood and confounding affects of non-corresponding features taken into account.

The central part of this paper provides a preliminary approach for characterizing similarities and differences between Devon and Mars and a strategy for defining experimental protocols. A distinction is drawn between high-fidelity characteristics that are inherent or can be easily imposed (e.g., authentic geology investigation) and characteristics that require more planning and may be imposed in more limited experimental phases (e.g., wearing realistic gloves). For example, how is a geologist’s observation, interpretation, and memory changed if drawing on site is not possible, but restricted to annotating photographs after returning to base camp? Ethnographic studies and modeling of practices establish a baseline of how people normally work. Behaviors that will be impossible or severely constrained on Mars can then be identified and their effect articulated, providing requirements for new tools and processes.

The Hab as Constructed

Figure 1 shows the upper deck layout of FMARS as it was initially configured for a trial occupation in July and early August 2000[3].

[3] The occupants during the first controlled occupation for three days were Bob Nessen (Discovery Channel representative), Darlene Lim, Larry Lemke, Carol Stoker, Marc Boucher (Mars Society representative), and the author. Trial occupation continued under less formal constraints for another four nights with other crew members.

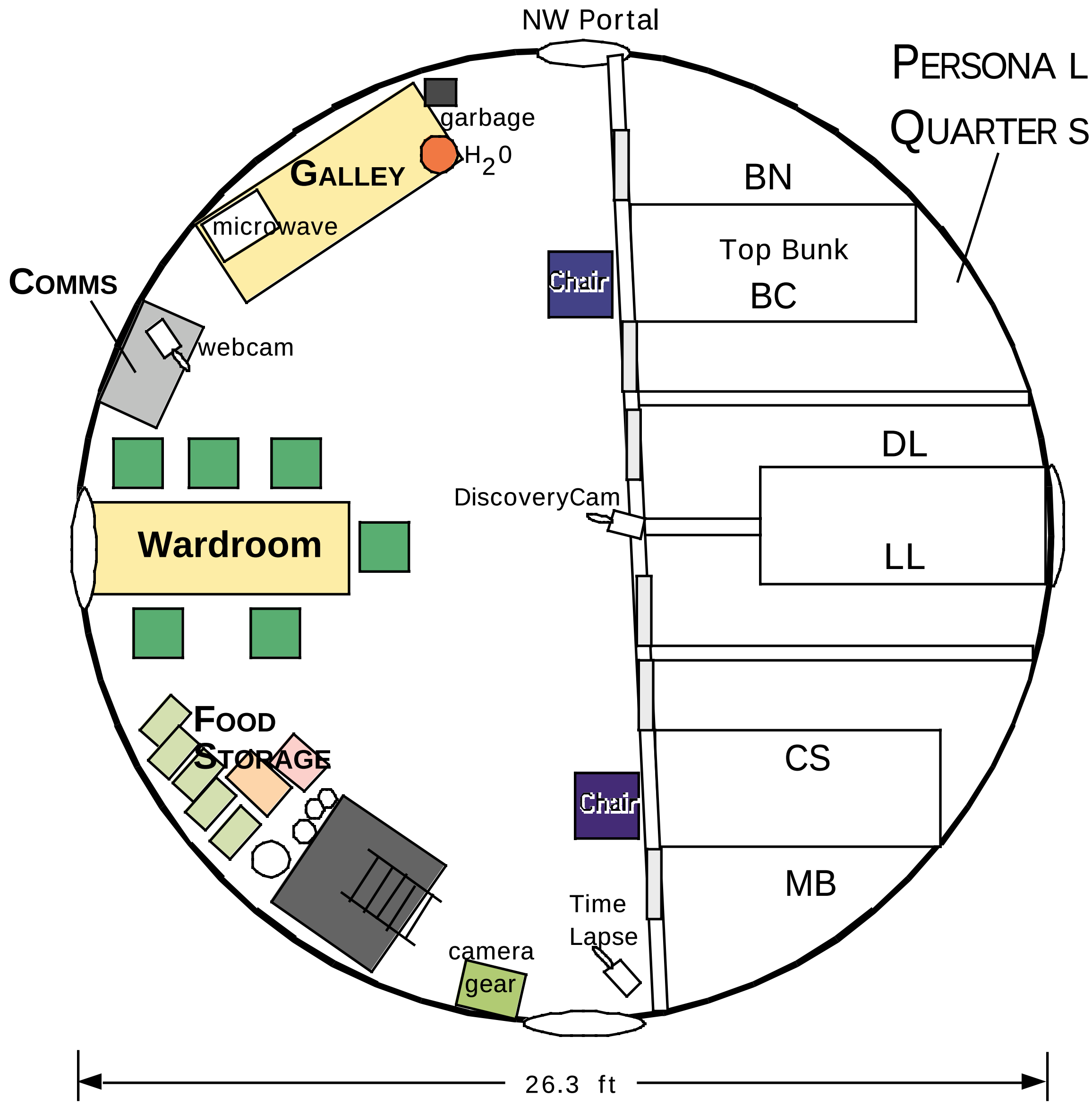

Figure 1. Flashline Mars Arctic Research Station, Upper deck as built July 2000 (to scale, accurate within 2 inches)

The blue chairs are personal camp chairs brought by two of the crew members; they were removed when the crew departed. The "Comms"(communication network) station was assembled on a Rubbermaid 50G container along with two power strips and battery rechargers for cameras and laptops. A WiLan Hopper Plus wireless internet hub (coming from satellite dish/repeater on a hill about 3/4 mile away) was connected to an eight-station ethernet "mini-hub."[4]

[4] This external network and other support was provided by NASA's Haughton-Mars Project, managed by Pascal Lee and Kelly Snook.

Three or four laptops were often in use, including a G3 Apple Powerbook connected to an AirPort base station on the “wardroom” table. We used this table for eating, meeting, and working on computers.

The “galley” included a stove, microwave, and water container. We stored utensils here, plus the drinks and condiments that were included in MREs (meals, ready-to-eat). Water was brought in from the base camp in 5 gallon containers. The bunks are staggered; for example, referring to Figure 1, BC’s area has a top bunk and BN sleeps below inside the same rectangular area.

Electricity was produced by a 2.5KW gas generator, connected to the hab downstairs via an extension cord, and distributed via three power strips and one Y-cord. About 12 plugs were in use at any time (chargers and camera transformers were not always plugged in).[5]

The rooms are not as evenly spaced as indicated in the figure; BC’s was actually a few inches broader than the others. MB and BN had the most usable space. In general, being on the floor was judged superior because it allowed accessing the space to the side of the bed while in bed (more like a tent). The upper bunks are about five feet high.

The lower deck (Figure 2) was only used for entry, personal hygiene, and Discovery Channel communications during the trial occupation. We also preferred to have internet connection in the living area, which was chosen to be the upper deck because it was much warmer and brighter. There were no lab activities planned for this time, which is a primary planned use for the lower deck.

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[5] One of the power strips went to the corner of BN’s room, which was used for lights in BN’s and DL’s rooms (each room has a light, but they cannot be easily mounted using the spring clip attached). An extension ran from the Comms area to the time lapse camera. Another extension cord came up near the ladder and connected to the DiscoveryCam (security camera).

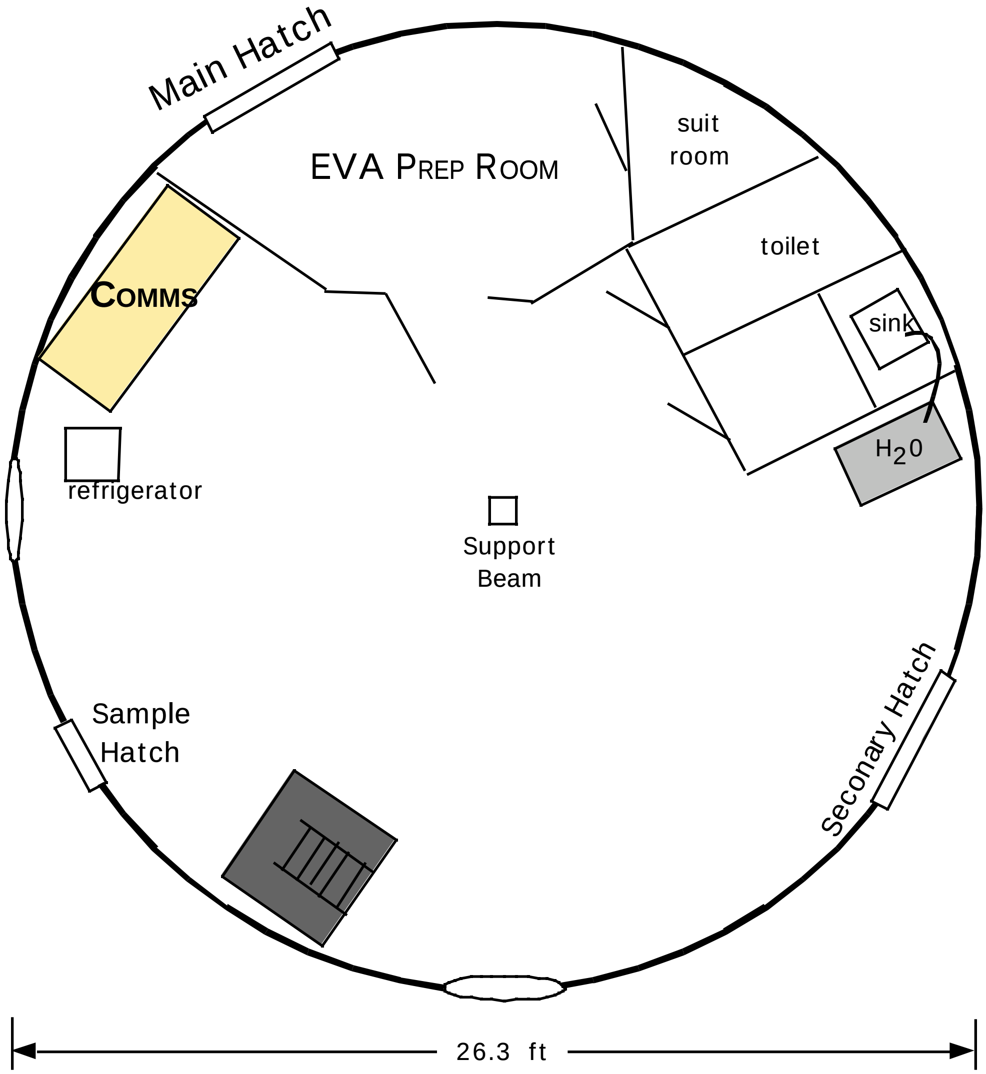

Figure 2. Lower deck as of July 2000

All aspects of the layout in July 2000 are considered to be temporary. Appendix 1 lists the work required before formal experiments can be undertaken. A continuing debate concerns whether the interior design should appear finished (e.g., one crew member suggested following aerospace standards, such as the interior of a 747) or be inexpensive and easily changeable (e.g., painted plywood and 2x4s). This matter should be resolved be the FMARS science committee. Preliminary experience indicates that FMARS provides a significant opportunity for experimenting with different designs, so cost and ease of modification are important.

Analog Study Dimensions

Use of FMARS will be managed by a science committee with representatives from NASA and the Mars Society. This committee will presumably solicit proposals for experimental work to be performed inside or around the hab. The work may involve tools, facilities, or procedures that crew members will implement, possibly with direct participation by the proposing principal investigator or representative. For example, during the year 2000 field season, Hamilton SunStrand sent two representatives to Devon Island to perform experiments with a prototype space suit. How will such experiments be selected and managed? As a first step, we might consider how such proposals might be categorized. I refer to these as *analog study dimensions*, ways of characterizing a proposed study in which the hab and its environs are treated as an analog for living and working on Mars.

Analog study dimensions include:

- **Discipline:** Human factors, biology, sociology, geology, telecommunications, computer science, industrial engineering, architecture, etc.

- **Work/Life Activity:** Data gathering/analysis, exploration, life support, recreation, planning, waste management, cooking & cleaning up, chores, retrieving/storing supplies, interaction with earth, sleep/eating/hygiene, etc.

- **Mission Phases:** Preflight, landing, set-up, exploration, reporting, pre-departure, crew handover

- **Engineering and Implementation:** Requirements analysis, design, documentation, validation, training

- **Known Challenges:** Atmosphere, gravity, radiation, dust, water, fuel

- **Technologies:** Communications, life support, automation,...

As an example of how different dimensions enter into analog research, consider a photograph (Figure 3) taken during the trial occupation, illustrating how people are using the facility and their tools (books, maps, laptops). Using such data, an architect might focus on how space is used (e.g., how people sit and read in front of their personal areas and use a chair for a foot rest). A telecommunications specialist might develop a wireless network for the hab to allow using a laptop in a stateroom. Focusing on work/life activities, one might observe how the crew has chosen to work quietly in the late afternoon, while remaining in visible contact with each other. Considering the work being done, a mission scheduler would observe that planning, reporting, and recreational reading are occurring at the same time, as different crew members have organized their day in different ways. Another study might consider how dust is managed (leaving outerwear on the lower deck). A life support study might indicate how the water supply (a primitive orange cooler here) is managed and recycled. Observing the duct tape so close to hand, we might inquire how the crew has been fixing or improving the facility. Indeed, the number of relevant observations from a single (well-chosen) photograph is incredible; an experienced multidisciplinary team would typically spend several hours analyzing a five-minute video of this same group setting (e.g., see Jordan, 1974).

This example illustrates that different researchers will adopt different perspectives for experimenting with and studying the hab. The dimensions listed above could be used in a request for proposals to indicate relevant areas of interest; the science committee could prioritize these areas depending on activities planned for a given field season. In general, proposals should be sought that strive for *synergy* (relating simultaneous experiments), *balance* (covering the range of possible research dimensions), and *system integration* (understanding and designing for interactions between facilities, organization, procedures, and technologies).

Figure 3. Example observation relevant to analog studies in the hab. Four crew members are working independently on the upper deck in the late afternoon. View is towards the west, showing staterooms with open doors (cf. Figure 1).

Expected Contributions

What research results might be expected from analog studies using FMARS? Although we cannot predict the serendipity of scientific work, it is useful to list obvious areas of contribution that might be expected:

- *Mostly inside hab*
  - Hab design
  - Daily life schedules and procedures
  - Crew selection

- *Mostly external to hab*
  - Space suit capability & durability
  - Scientific instruments (types, deployment, monitoring)
  - Communication protocols (mission support, PIs, public)

- *Computer technologies*
  - Telecommunication/ computer equipment (hab, rover, space suit, earth)
  - Automation requirements (life support, rovers, science, & exploration)
  - Telescience, telemedicine, teletraining

This list could be helpful to organize experiments to cover the opportunities FMARS allows. For example, an effort might be made to include at least one experiment that takes into account crew selection. Similarly, given plans to have multiple habs in different locations (e.g., Arizona, Iceland), proposals for a given hab may focus on interacting factors, such as the relation of space suits and rover design. Presumably the FMARS science committee will develop this list early on to develop a shared set of objectives that can be communicated with researchers and the public.

Understanding Fidelity in Analog Studies

The environment and logistics of working on Devon Island and Mars differ in many important ways. What transfer of data and lessons can be claimed, given the confounding variables that are not part of a study? For example, must every extra-vehicular activity (EVA) occur in a space suit in order to replicate the safety problems of an unpressurized environment? Is there a principled way of "analyzing away" differences, to produce data that will be valid on Mars?

We might begin by asking what characteristics make the Haughton site and scientific work in the crater unique or of special importance as a Mars analog. Two kinds of characteristics may be easily identified, those that are inherent in the site (Table 1) and those that are imposed (Table 2).

Table 1. Inherent high-fidelity characteristics at Devon Island relative to Mars surface operations

- Habitat with realistic dimensions and life support
- Work has ecological validity—field science in a cold, rocky, windy, dusty, periglacial environment
- Life support, power, transport, and instrument systems require regular monitoring, resource management, and maintenance
- Satellite data services (GPS, weather, communications) and local wireless networks are available and necessary
- Remote field instruments are deployed and monitored
- EVA sites must be revisited, but access is limited

- Distant sites provide logistic support (especially Resolute)
- Local weather must be monitored for safety and planning
- Protective clothing is necessary

Table 2. Operational constraints that might be imposed at Devon Island to replicate Mars surface operations

- "Science Backroom" (perhaps distributed over the Internet) monitors and advises; provides tasks and training
- EVAs: Walkable return, use walkie-talkies, wear space suits, plan and monitor, video available at base camp and mission support
- Shared scientific database, reused and extended by multiple crews, downloaded to mission support; field dictations transcribed by mission support
- New crew members trained on systems, geography, suit, etc.
- PIs at NASA centers and universities participate in data interpretation, instrument use, and EVA planning
- Robots serve as advance scouts, field assistants, caching
- Crews install additional equipment and upgrades

Proposals for FMARS experiments should refer to the inherent constraints to indicate how the proposed work leverages the site and its existing support structure. Proposals also need to make explicit what fidelity characteristics are missing and how these will be handled by operational constraints, such as those listed in Table 2.

It might be thought that the Devon Island environment is not extreme enough or our tools such as gas generators are too convenient and unrealistic for Mars. But life on Devon is closer to the edge than might be supposed. If a few more power strips were to break, as happened during the first night of the trial occupation, we would be unable to service all the computer and telecommunications gear on the upper deck. EVAs using an all terrain vehicle (ATV) may appear easy, but if a crew were sent out to the boulders of Lost Valley in the Haughton Crater, it might be difficult for them to navigate and return (in 1999 a group spent several hours clearing a path). Furthermore, during HMP-2000 there were several accidents involving ATVs, one of which was life threatening and required a helicopter transport to Resolute.

Nevertheless, surviving on Devon, if not trivial, is arguably easy compared to living on Mars. So we must consider the fundamental differences between Devon Island and Mars (Table 3). Proposals for experimental work must indicate which of these differences could be confounding variables (invalidating lesson transfer to Mars surface operations) and how these might be ameliorated. In particular, the mix of operations might be similar to what will occur on Mars, even if specifics are different. For example, although the power on Devon Island will not be nuclear, the crew still needs to manage the available supply and monitor the proper operation of the facility. As indicated next, the differences between Devon and Mars might not only be argued away, but serve to generate study ideas.

Table 3. Characteristics of Devon Island site that distinguish it fundamentally from Mars

- Atmosphere (breathing apparatus and pressurized suits not required)
- Surface water (local streams)
- Food (replenished twice weekly via plane)
- Fuel (power by gas or diesel combustion)
- Medical care (available within 100 miles at Resolute; hospital several days away)
- Time delay (only about one second via satellite)
- Sunlight (24 hour days April-August)
- Gravity (normal 1g vs. .38g)

A Difference-Based Approach for Analog Studies

Differences between Mars and Devon could be a primary driver for defining analog studies. One might assume that a major difference, such as the availability of ready medical care, would preclude using FMARS to understand that aspect of life on Mars. Or perhaps other issues under investigation would be "contaminated" by the lowered requirement for safety, crew training, local diagnostic instruments and medication, remote support, etc. However, rather than viewing major differences between Mars and Devon as reducing validity of what we learn there, we could use the difference as a way of highlighting what will be different on Mars, and then design tools and processes to address the difference.

For example, taking the case of medical emergencies, one could enumerate problems that are currently handled in Resolute (or the more distant town of Yellowknife) and ask what knowledge and tools would be required to handle those problems at Devon Island itself. One result might be the conclusion that certain types of surgery, for example, will not be possible on the Mars surface until a permanent base camp, similar to Resolute, is established. Another approach would be simulate medical emergencies, such as during an EVA, to understand and later validate communication tools and protocols for handling such problems.[6]

In short, a heuristic for generating FMARS experiments is to focus on key differences between Devon and Mars. With a given theme in mind, such as medical care,

[6] James Oberg conducted a simulated exercise in July 2000 at "Pushing the Envelope II: Medicine on Mars," sponsored by the Center for Aerospace Medicine and Physiology at the University of Texas Medical Branch in Galveston, Texas. See www.jamesoberg.com articles: "Mars Medical Emergency."

ethnographic studies would establish a baseline of how people normally work (e.g., observe the medical facilities at Resolute; how do they receive advice from distant physicians and what problems must be handled in Yellowknife?). Practices that would be impossible or severely constrained on Mars can be then identified and their effect articulated, providing requirements for new tools and processes. For example, the medical equipment at Resolute would be described and serve as a preliminary specification for what must installed in the hab. At some time during preparation for Mars missions, such equipment would be actually installed at one of the analog sites and crews that were not medical specialists trained in its use. This example illustrates how research related to FMARS does not necessarily entail being on Devon Island itself, but studying its support structure.

Because the idea of difference-based research is so important, another example might be useful. Consider the implications of the Mars atmosphere. Astronauts will need to wear pressurized suits. Current designs preclude fine hand manipulation for long periods of time, as is required to draw or write. Observing geologists at Devon, we find that they frequently sketch rock formations in great detail during EVAs. How is a geologist's observation, interpretation, and memory is changed if drawing on site is not possible, but restricted to annotating photographs after a traverse is complete (or in a pressurized rover)? We could impose an experimental protocol to investigate this question. We might find that there is no difficulty, that work quality is greatly reduced, or that there are important individual differences. Given these findings, we would then know what importance to place on inventing a spacesuit glove that permits long periods of drawing. Notice that without such analysis, one might plunge head-first into glove design (certainly an awkward approach!). By understanding the implications of problems and considering first the breadth of alternatives available to ameliorating difficulties, we have a better chance of quickly developing cost-effective designs.

Likely Scenarios and Study Methods

The discussion to this point has been mostly bottom-up, considering components of research dimensions and fidelity characteristics, and how they might be used to define possible experiments. Another approach is to list study scenarios, based on the setting and past operations of the Haughton-Mars Project. These are in some sense obvious things to investigate, given the opportunity provided by FMARS.[7]

- Daily life in the hab: What will be the schedule in the long term? Should there be quiet times and places? What changes might be allowed for variety during the mission?
- Crew organization: The commander notion fits the airplane model with "a pilot in command," but is it the only model we should consider for Mars?
- Traverse planning, navigating, and monitoring: If there are only four crew members and one is monitoring two outside, will the fourth person be overloaded in handling

[7] Example questions were raised during a discussion with the initial crew on August 1, 2000.

routine tasks, troubleshooting, and reconfiguring systems for the next crew activities? (This problem is anticipated to occur on the International Space Station.)

- Setting up and manage a remote field camp: Look at off-nominal cases; set up problems as in standard mission sims, e.g., a bad ATV is seeded during the night, a simulated injury occurs.
- Tending field instruments: Should there always be wireless transmission of telemetry to a central database?
- Communication with mission support, co-PIs, and the public: How will the crew find time to record and format official reports? Given the impossibility of second-by-second tracking, to what extent will mission support know what is happening on Mars?
- Maintaining and troubleshooting equipment, especially the power system: What's needed for a repair/machine shop? How much time is required during a mission? Is "just in time learning" practical, with training materials supplied by mission support?
- Mixed-initiative teleoperated exploration. Could robots retrieve sensor-loggers?
- Analyzing data in the hab and researching related work over the internet. Will members of the science backrooms co-author papers with the crew, while they are on Mars?

As an example scenario, Figure 4 shows a biologist and assistant visiting a remote site during the HMP-2000 field season. The biologist had placed temperature and UV instruments under and around plexiglass containers one year before. In addition, some of these had been treated with fertilizer. The site is near the Haughton River within the impact crater, about 10 km from the hab. In order to establish a "baseline" of normal practice, the biologist was observed and his actions documented, when the treatment and apparatus was placed and when it was revisited a year later. For instance, we observe in this photograph that the biologist is instructing an assistant what information he wants to record during this visit and how it should be organized on the page. Here he is recording the observed growth of plants (Arctic willow) in different areas, which he designates by codes, such as "lower F." Thus, he speaks out loud as he observes each area and takes photographs, while the assistant logs the observation and photograph number. Later the biologist will transcribe this information into a computer file and use it to create a figure in a publication.

Figure 4. Tending sensors that periodically log data at a remote site, about 10 km from FMARS.

With this understanding we can then begin to inquire about the implications for Mars surface operations. How often must the biologist revisit this site? Could a rover with a speech-understanding program provide the same assistance in logging data? Could the camera be connected to the communications channel, so the biologist's statements would be directly associated with given photographs? How would the photographs be integrated into a site record over several years and these integrated into the expedition's overall study of the crater? Should the observations and photograph be directly transmitted by wireless link to base camp? Is this data to be considered non-public until publication or is it available for immediate release on the expedition's web site? Would it be possible to eliminate the return visits to some sites by continuously transmitting the sensor data to base camp and then having a robot retrieve the sensors when the experiment is complete? These are the issues and design possibilities that arise from the simple process of following a scientist in the field, observing how work normally occurs, and considering the implications for Mars.

FMARS Principles of Operation

The key point of this paper is that exploiting FMARS requires a systematic approach for managing the facility. This section makes explicit recommendations that could become a mission statement and formal procedure for evaluating and implementing FMARS research proposals.

Foremost, everyone involved in this enterprise should remember that the essential opportunity provided by an analog facility is to *carry out experiments that test and exploit contextual interactions*: Facilities, crew roles, clothing/suits, instrumentation, operations, medical care, documentation, training, life support and exploration automation, external support, communications, etc. This is commonly called a "total system" approach (e.g., see Greenbaum and Kyng, 1992). This will distinguish the FMARS facility from previous work in isolated and confined environments. Proposals that use FMARS as if it were just another small habitat or proposals that refer to only a single technology would be missing the point.

Living and working in FMARS will allow aspects of Mars surface operations (e.g., glove design) to be considered together. Problems and solutions shouldn't be narrowly conceived, but understood and approached from multiple disciplinary perspectives. For example, a perceptual-motor problem with spacesuits might be resolved by a change in collaboration between astronauts on an EVA and remote support. Interactions between people, procedures, and the environment might be non-obvious until they are tried on Devon Island. For example, astronauts during Apollo lunar traverses requested information from Capcom in Houston, rather than troubling their nearby companion, who was busy doing something else. This practice developed on the moon; it was not part of the operations checklist and preflight training.

With these observations in mind, the following are recommended principles for managing the FMARS facility:

- *Clarify the unique human abilities to explore Mars and how automated systems may complement them.* Use the authentic work setting to emphasize what today's robots cannot do, while looking for opportunities to automate routine operations and detect and diagnose emergency situations.
- *Exploit the opportunity for total system design and evaluation.* Specify how a given proposal leverages other activities and the hab's setting. For example, how does spacesuit design integrate with the hab's life support design? Experiments should be well conceived and pointed at specific problem interactions.
- *Minimize the role of aspects better treated elsewhere*. For example, study of long-duration occupation is confounded by the 24 hour sunlight during the summer and darkness during the winter.
- *Treat the Devon setting as the mission, preceded by simulations* that certify equipment and train the operators and crew. Don't take untested equipment to Devon Island.[8] Operating FMARS is too expensive to "wing it."
- *Employ critical engineering analysis in scenario design and analysis.* Let imagination evoke, not convince. Continuously ask "what if" and work through the implications of an actual Mars setting.
- *Exploit the environment to increase realism*. For example, subzero weather in spring would likely convince the crew that safety protocols are important, so EVA plans must be followed.
- *Design for increasing authenticity.* At first the context will be supportive (i.e., base camp services), then more capabilities will be moved inside the hab to

[8] For example, the weather station deployed during HMP-2000 should have been tested under cold and windy conditions with low sunlight to understand the effect on batteries and antifreeze.

increase isolation and self-sufficiency. Services include especially power, food, fuel, communications, and waste management.

- *Distinguish the media show from engineering experiments.* Don't overdo simulated "being on Mars" for the sake of the media. In particular, requirements for film angles, lighting, and reshooting scenes must never infringe on experimental protocols.
- *Manage by science committee with written policies and peer review,* with overall long-term objectives in mind. A successful collaboration between NASA, vendors, universities, and the public members of the Mars Society requires that FMARS is operated first and foremost as a scientific research station, with the standard procedures for participation and publication of results. This implies a formal request for proposals and written evaluations.
- *Complete the habit before starting any further experiments.* All workers, noises, construction materials and tools, etc. are intrusive. Minimal requirements are listed in Appendix 1.

Broadening Participation

The nature of the hab is that only six people will be participating in formal experiments at one time inside or working around FMARS. However, a much broader participation is possible by adopting the methods used in Apollo, Skylab, and Shuttle operations:

- PIs could propose experimental "payloads" that would be taken to Devon Island; crew members would be trained in procedures for deploying and carrying out experiments. Data would be shared with the PI (with time delay), and experiments modified accordingly. NASA has extensive experience in managing work in this way. However, handling unexpected problems and maintaining communication with the crew has not been satisfactorily resolved. See for example the problems with the US Microgravity Lab during STS-50 (USML-1, 1992)

- Vendors will want to bring their representatives to Devon Island to observe first-hand how their technologies perform. For example, Hamilton SunStrand sent two representatives to HMP-2000 to test a spacesuit. For certain experiments isolating the crew is useful, so direct observation will not be possible. It may be useful to perform two kinds of tests, those in which representatives may participate directly and those that the crew undertakes independently (but documents as for payload studies).

- A small team performs the role of "mission support" from a remote site, communicating with the FMARS crew via emailed documents, including photographs, video, and audio recordings. Preliminary trials were performed during HMP-2000 by the Human Exploration Team at Johnson Space Center, as well as by a Mars Society team in Denver.

- One or more "science backrooms" monitor the communications between the crew and mission support, providing technical advice and warning of potential problems. A key task is to analyze data for trends (e.g., excessive use of key resources). Close colleagues of crew members are presumably participating in a backroom.

- Additional members of the scientific community, who specialize in areas under investigation, would communicate informally with the science backrooms. These people may observe information that is publicly available on an internet web site and use email to contact formal support operations with advice and warnings.

- Members of the public will receive a great deal of information from public web sites. Over a long duration mission, it would be advantageous to involve students around the world in some experiments.

Funding will be a limiting factor that determines how people can participate. Because of the scientific nature of the work, participation will be strongly influenced by membership in an appropriate organization, such as a university department, that undertakes such research, as well as by the individual's ability to secure funding, such as from NSF. Belonging to the Mars Society may be necessary for participating in FMARS scientific research, but because of the research focus it is obviously not sufficient.

Conclusion: Remember Our Goal

It is worth considering that just as we will not go to Mars solely for science, the purpose of FMARS is broader, too. The designers, funders, and construction workers built the facility in part to inspire the public about a grand vision. We may be reminded of the advice of Daniel Burnham, the "architect of Chicago":

> Make no little plans, they have no magic to stir men's blood. Make big plans, aim high in hope and work, remembering that a noble, logical diagram once recorded will never die, but long after we are gone will be a living thing asserting itself with ever-growing insistency. (Moore, 1921)

FMARS is part of a big plan, realized on Devon Island as a living thing, asserting with ever-growing insistency our intention of going to Mars. The management of FMARS should aim high in hope and work—not become lost in political squabbling or technical details, but remain true to the magical vision of human exploration of space. Through the credibility of FMARS research and the beauty of the setting, let us inspire the public that living and working on Mars will not only be possible, but is noble and worthy of our best efforts.

Appendix 1: Changes Required to Prepare FMARS for Formal Experimentation

The following changes are minimal recommendations for improvements for future habitation:

- Environment and safety: waterproof roof; ventilation fan at NW portal upper deck; at least 5KW electric generator capacity; smoke and CO detectors; escape ladder from upper deck; heating downstairs.
- Staterooms: Ladder to access upper bunks, shelving and six or more hooks for clothing; electric lights mounted; electric outlets in each room.
- Galley: Sink with a drain and running hot and cold running water; storage for personal and common utensils, plates, etc. A wall cabinet for storing drink mixes and snack food. Food and/or water storage above staterooms with ladder to access. Large thermos for hot water; tea kettle.
- Work area upper deck: An additional table (with optional built-in full-perimeter desk), shade on SE (middle) portal, desk lights if staying beyond first week of August, wireless network (IEEE 802.11 compliant), one walkie-talkie for each person
- Stairs to replace ladder (with optional railing at upper deck and optional pulley to bring items up and down)
- Toilet/Bath rooms on lower deck: Shower stall, urine collection, built-in toilet seat, interior light, towel hooks and places to store personal items
- Work area on lower deck: Internet hub, desks/chairs downstairs, resolve florescent flickering

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